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Spaceport Engineering and Technology Directorate
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SUBJECT: Failure Analysis of Wheel Studs (P/N 9-049-104995) from an RT 990 60 Ton Crash Crane (S/N 75190)

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## 1.0 ABSTRACT

Five wheel studs (P/N 9-049-104995) from an RT 990 60 ton crash crane (S/N 75190) were submitted for failure analysis after they fractured either in service or while being torqued. SEM and metallographic analyses determined that the wheel studs likely failed due to fatigue exacerbated by corrosion. Cracks originated in the roots of the last threads and extended through approximately half of the cross sectional area of the studs, rendering them unable to withstand the service or nominal torque loads. In seven cases, final overload occurred in service; an additional four studs failed during retorquing.

## 2.0 FOREWORD

2.1 A fractured wheel stud (P/N 9-049-104995) from an RT 990 crash crane (S/N 75190) was submitted for failure analysis after it was found on the ground near the crane. Six additional wheel studs failed in a similar manner, but were not submitted. All of the failed studs were from rear wheels: four from the left rear wheel and three from the right rear wheel. Four additional studs were submitted after they fractured during torquing. A used intact stud of the same design was submitted for comparison purposes.

2.2 The studs are reportedly ASTM A490, Type 3 bolts. The studs are intended for one time use and should not be retorqued, per AISC 5-276, *Specification for Structural Joints Using ASTM A325 or A490 Bolts*. The function of the studs is to attach the hubs to the wheels. Figure 1 shows the crane and the rear wheel hubs with the locations of the seven studs that failed in service.

Figure 1

RT 990 crash crane (top), with left and right rear wheel hubs (bottom). Arrows indicate locations of failed studs; circle indicates location of stud submitted for analysis.

## 3.0 PROCEDURES AND RESULTS

3.1 The fractured studs and the intact stud were photographed as-received (Figures 2 and 3). Corrosion products were present in the threads of the intact stud. Three of the fracture surfaces displayed dark/discolored regions, likely pre-existing cracks (Figure 4). Macroscopic fatigue-like features, i.e., crack arrest marks and radial features, were observed on two of the fracture surfaces (Figure 5).

3.2 The intact stud was submitted for nondestructive evaluation. Fluorescent magnetic particle analysis revealed no cracks or indications.


Figure 2

Four fractured studs, as-received. Arrows indicate fracture surfaces.


Figure 3

Used intact stud, as-received (left), with a higher magnification view of corrosion products in the threads (right).

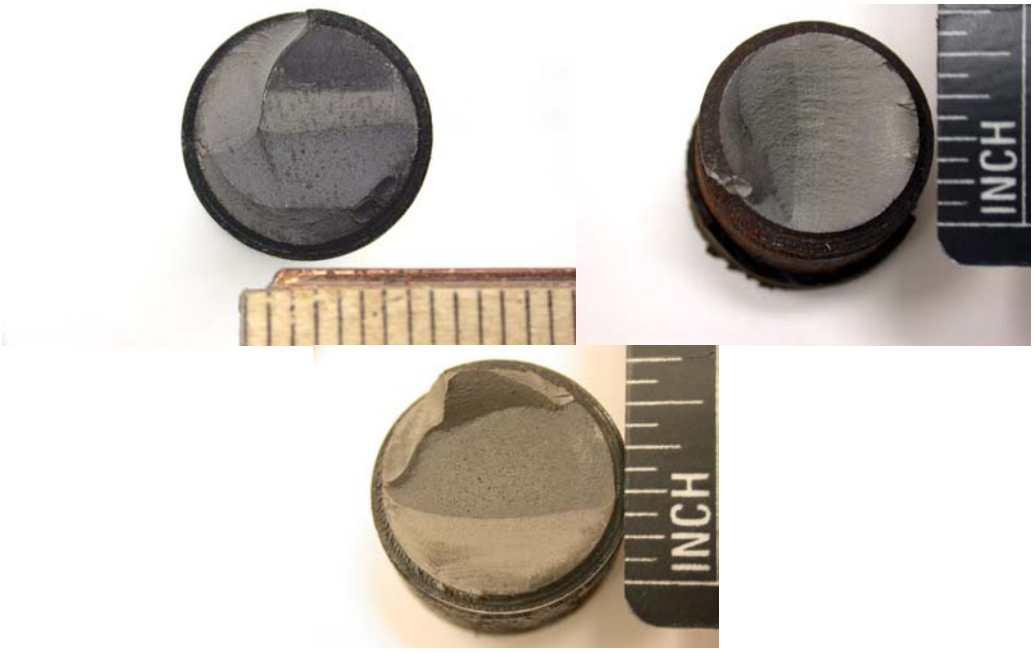


Figure 4

Fracture surfaces of studs 0 (top left), 2 (top right) and 4, showing discolored regions.

Figure 5

Fracture surfaces showing crack arrest marks (stud 1, left) and radial features (stud 3, right). Arrow indicates origin area. Magnification: 3X

3.3 The failed studs were sectioned and cleaned in preparation for analysis by scanning electron microscope (SEM). All of the fracture surfaces displayed extensive corrosion damage in the discolored regions (Figure 6). The stud 1 and 3 fracture surfaces were heavily corrosion damaged in the regions displaying macroscopic fatigue-like indications. Intergranular features were observed near the edge of the stud 3 fracture surface, opposite the origin area (Figure 7). The final overload regions of all of the studs displayed dimples formed by microvoid coalescence (MVC), indicative of ductile overload (Figure 8). As is common in high strength steels, no microscopic features indicative of fatigue striations were observed.

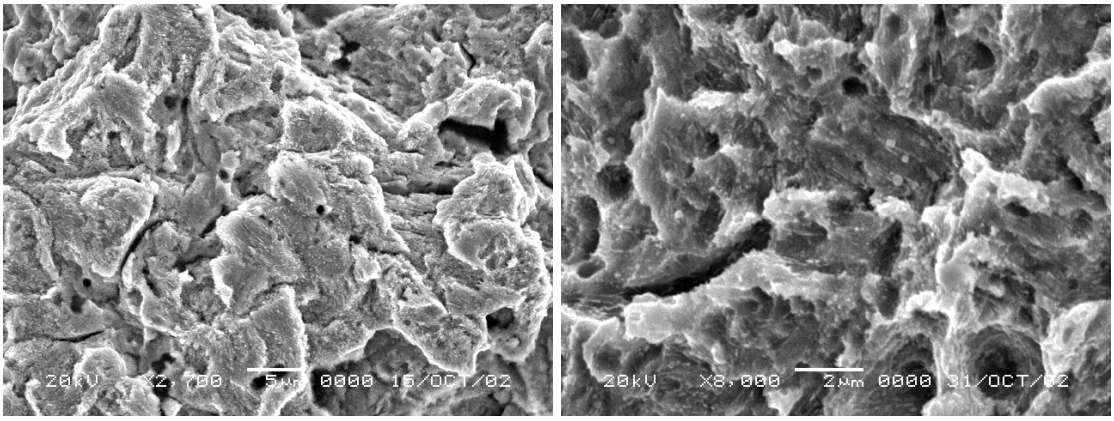


Figure 6

SEM micrograph showing corrosion damage on stud 0 (left) and stud 1 (right) fracture surfaces. Magnification: left - 2,700X; right – 8,000X

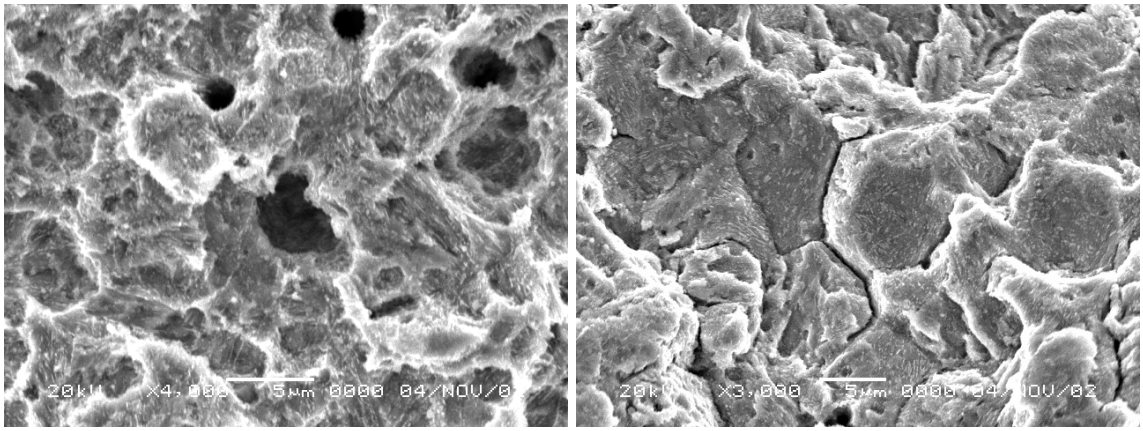


Figure 7

SEM micrograph showing corrosion damage (left) and intergranular features (right) on the stud 3 fracture surface. Magnification: left - 4,000X, right - 3,000X

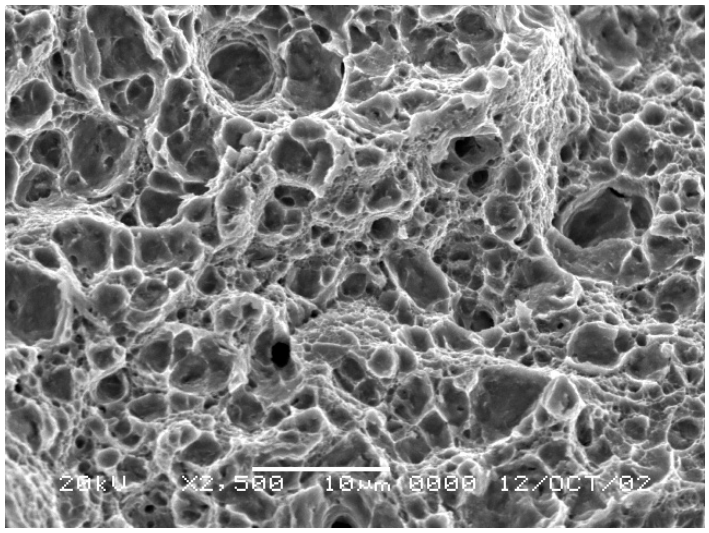


Figure 8

SEM micrographs showing dimples formed by MVC on the stud 0 fracture surface. Magnification: 2,500X.

3.4 The studs were sectioned longitudinally and prepared for metallographic analysis. The microstructure consisted of bainite and tempered martensite with manganese sulfide stringers (Figure 9). Secondary cracks were observed in the corrosion damaged regions of the fracture surfaces, often associated with stringers open to the surface (Figure 10).

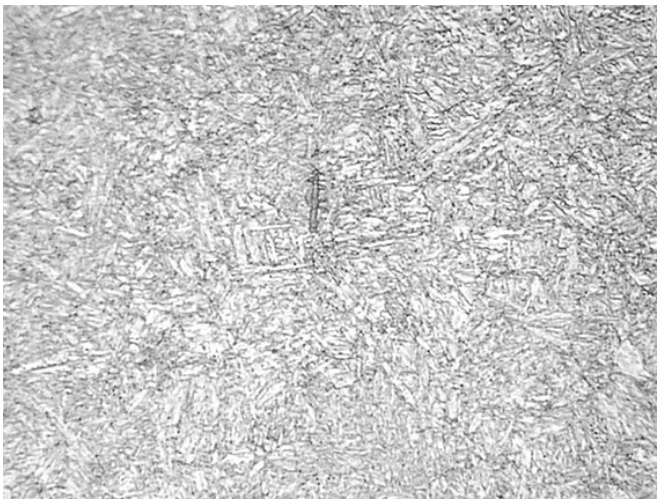

Figure 9

Micrograph of a cross section of stud 2. The microstructure is bainite and tempered martensite with manganese sulfide stringers. Etchant: 2% nital. Magnification: 1,000X

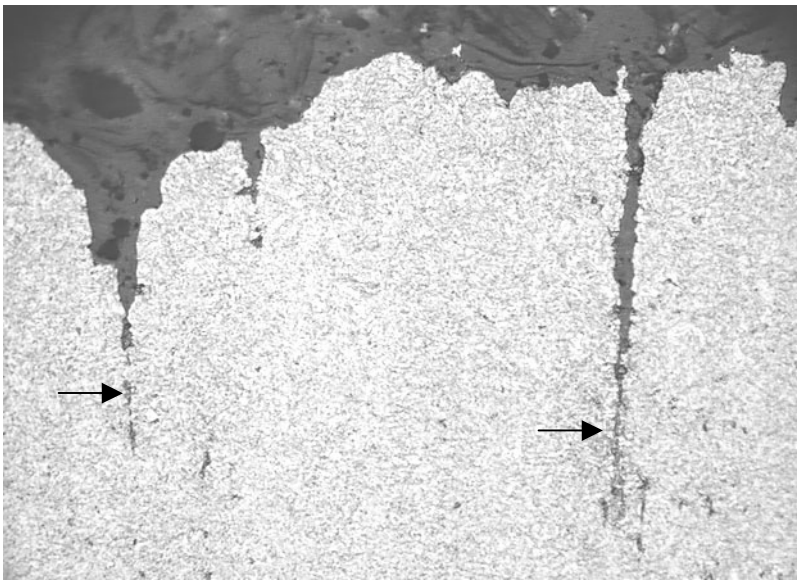

Figure 10

Micrograph of a cross section of stud 3 showing secondary cracks associated with stringers (arrows). Etchant: 2% nital. Magnification: 500X

3.5 Hardness measurements taken on a cross section of stud 0 averaged 37 Rockwell C scale (HRC). The acceptable hardness range for ASTM A490 Type 3 bolts is 33-38 HRC.

3.6 Chemical analysis by inductively coupled argon plasma spectroscopy verified that the stud material was ASTM A490 (Type 3 bolts).

## 4.0 DISCUSSION AND CONCLUSION

4.1 Macroscopically the cracking appeared fatigue-like, however, no microscopic fatigue features were observed. The absence of microscopic fatigue-like features is common in high strength steels and does not preclude progressive failure. The macroscopic features indicated that the bolts failed under low nominal stress conditions with mild stress concentration.

4.2 The wheel studs likely failed due to fatigue exacerbated by corrosion. Cracks originated in the roots of the last threads and extended through approximately half of the cross sectional area of the studs, rendering them unable to withstand the service or nominal torque loads. The studs are intended for one time use and should not be retorqued, per AISC 5-276, *Specification for Structural Joints Using ASTM A325 or A490 Bolts*.

EQUIPMENT: SEM, S/N MP17700061
Metallograph, S/N 237386
Rockwell hardness tester, S/N 81987709

RELATED DOCUMENTATION: KSC-MSL-0597-2002-01
Wylie NDE report 88869

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